

The Spectrum of the *HOT* Interstellar Medium  
The Diffuse X-ray Spectrometer (DXS) Recent Results  
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## Abstract

The Space Physics Group and the Space Science and Engineering Center of the University of Wisconsin have designed and built a pair of novel detectors, the Diffuse X-ray Spectrometer (DXS), for the spectroscopic study of the diffuse X-ray background. Each detector consists of a one foot by two foot, curved lead stearate crystal panel and a position-sensing proportional counter. The crystal panels reflect X-ray photons into the proportional counters according Bragg's law. The detectors, collecting X-ray photons between 42 Å and 83 Å with  $\Delta\lambda$  (FWHM)  $\sim 2.5$  Å, were exposed to the X-ray background for about 40,000 seconds on Space Shuttle flight STS 54 in 1993. Observations were made of a 15° by 150° swath at low Galactic latitudes away from the galactic center. We present the DXS spectrum of a typical diffuse X-ray background region and demonstrate the accuracy of the wavelength scale (0.3 Å), flat-field response (corrected to better than 3%), absolute flux calibrations ( $\sim 10\%$ ), and detailed agreement of the spectral shape of the instrument response to three mono-energetic input sources. The quality and accuracy of the in-flight spectra and detector response functions constrain theories of the origin and nature of the diffuse X-ray background. Fits to several plasma emission models are shown.

# Introduction

Soft X-ray ( $\sim 1/4$  keV) flux has been detected in the plane of the Galaxy, suggesting that at least a component of the soft X-ray background is not cosmic but local to the Galaxy, or the solar neighborhood (Bunner et al. 1969). The smoothness of the distribution of the flux on the sky argues against the possibility that discrete Galactic sources (e.g. stars) responsible (Levine et al. 1977). An observation in the direction of the Small Magellanic Cloud set a limit on the contribution of a cosmic component of the diffuse X-ray background at energies below 283 eV to 25% (McCammon et al. 1971). ROSAT detected a clear shadow of the moon in the soft X-ray background (Schmitt et al. 1991). The question is then, what is responsible for this flux of soft X-rays that originates somewhere between the moon and the Magellanic Clouds?

Williamson et al. (1974), suggested that the soft X-ray background likely originates from “widely distributed regions of interstellar gas with temperatures in the region of  $10^6$  K,” or the *hot interstellar medium*. Support for a thermal origin of the X-ray background comes from the detection of OVI in absorption along sight lines to nearby early-type stars (Jenkins & Meloy 1974). Such a high ionization state, in the absence of an ionizing flux of photons, implies collisional ionization in a gas with temperatures in the neighborhood of  $3 \times 10^5$  K. A gas at this temperature will also radiate X-rays, primarily in the form of atomic emission lines (Raymond & Smith 1977). An important test of the consistency of the thermal plasma hypothesis is the detection of emission lines in the spectrum of the soft X-ray background.

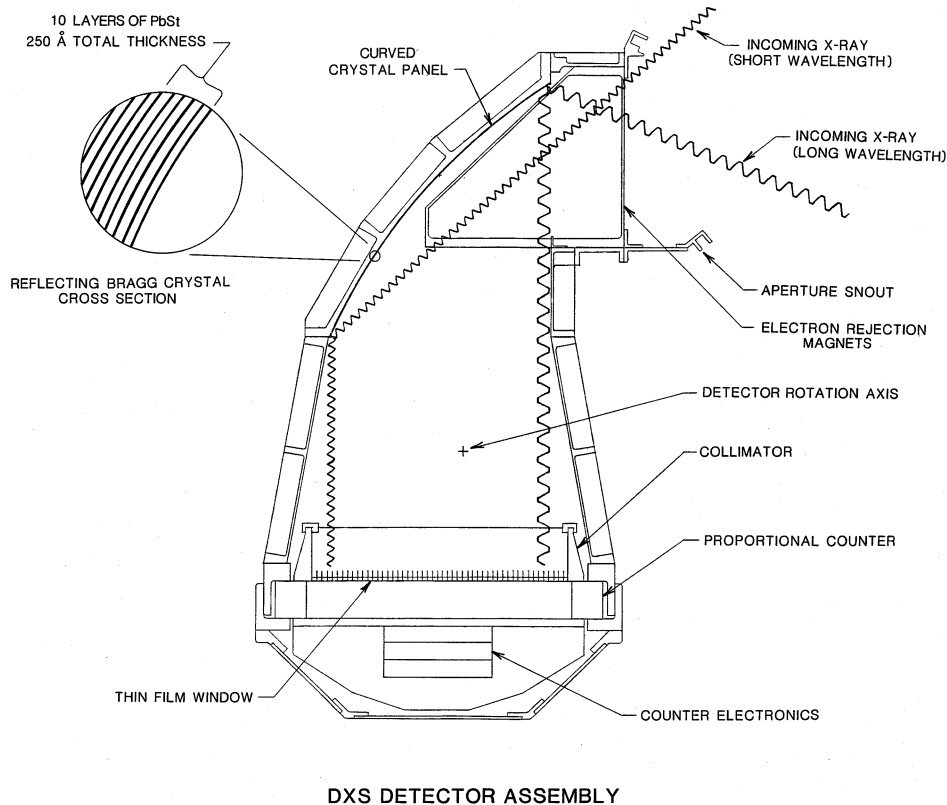


Figure 1: Cross-sectional view of one of the DXS instruments showing photon paths and some of the instrument's major parts.

## The DXS Instrument

The Diffuse X-ray Spectrometer (DXS) is an instrument designed to detect thermal emission lines near  $\sim 1/4$  keV. Figure 1 shows a cross sectional view of the instrument. Photons reflected according to the Bragg law from the curved crystal panel surface are detected with a collimated position sensing proportional counter. The instrument is rotated about its center of mass to detect X-rays of different wavelengths coming from the same direction.

Figure 2: Comparison of predicted and measured  $A\Omega$  for the port DXS instrument.

## DXS $A\Omega$ Calibration

The response function of the instrument has been well studied. Figure 2 shows the predicted effective area-solid angle product ( $A\Omega$ ) (solid line) and the measured  $A\Omega$  at three energies.

The response of the proportional counter was studied by shining the carbon calibration source directly into the proportional counter. The quality of the flat-field correction can be seen by the smoothness of the distribution of data points in Figure 3 (below). We estimate the large scale errors due to the flat-field correction are no greater than 3%.

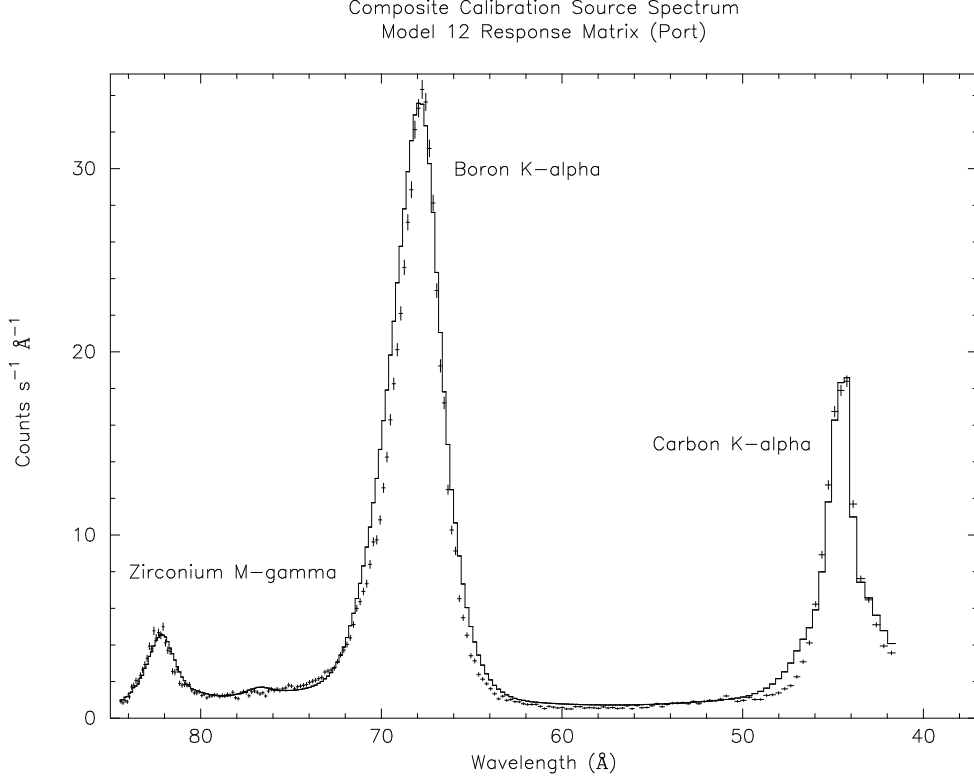


Figure 3: Model fits to three DXS post-flight calibration sources.

## DXS Spectral Calibration

Figure 3 shows the quality of the spectral fit to a combined spectrum of the three calibration sources. The excess broadening in the model fit at boron is most likely due to the broadness of the input function, which we took from Holliday (1967), rather than a problem with the response matrix. The problems with the precise shape of the model curve at carbon are most likely due to the functions used to model the crystal panel rocking curve. The best fits are achieved if the wavelengths of the lines are allowed to vary by  $\sim 0.5\%$  from their nominal values.

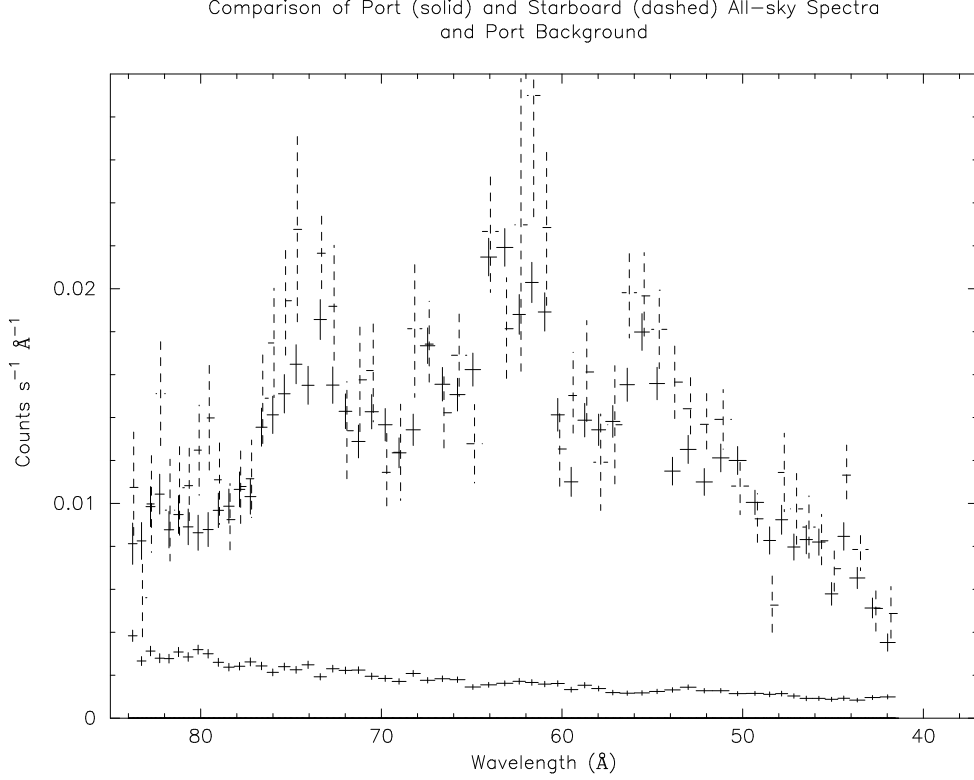


Figure 4: This figure demonstrates the self consistency between the two DXS instruments. The background for the port detector is also shown.

## In-flight Performance I

Figure 4 shows the comparison of the spectra obtained by the port and starboard instruments over the whole flight as well as the background in the port counter. Breakdown in the starboard proportional counter severely limited the amount of usable data from this instrument. Because of the risk of contamination from breakdown events, the spectral analyses below use only data from the port instrument.

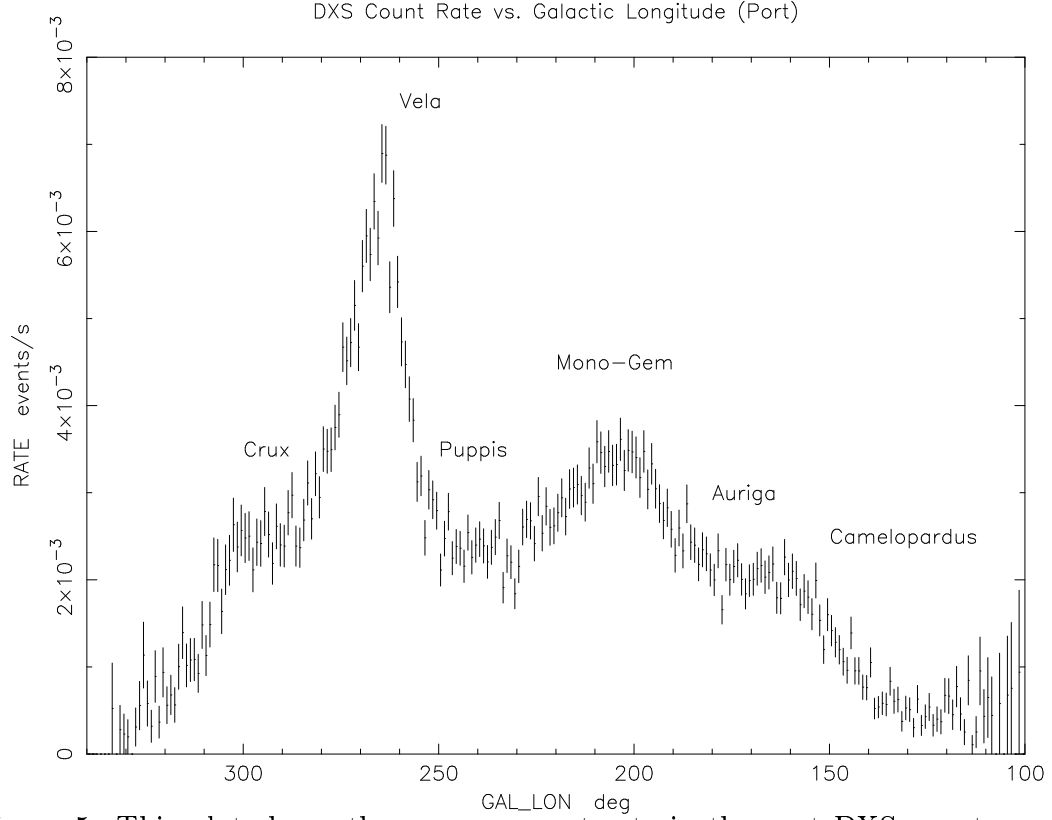


Figure 5: This plot shows the average count rate in the port DXS counter per detector channel as a function of Galactic longitude.

## In-flight Performance II

DXS observed a  $\sim 150^\circ$  by  $15^\circ$  patch of the sky at low Galactic latitudes away from the Galactic center. A plot of the count rate in the instrument vs. Galactic longitude is shown in Figure 5. The enhancements in counting rate are due to the Vela and Mono-Gem supernova remnants. The emission in the region between these remnants (in the Puppis constellation) is typical of the soft X-ray background. The count rate falls to background levels outside of the  $160^\circ$ – $310^\circ$  Galactic longitude range because of shadowing by the edges of the space shuttle cargo bay.

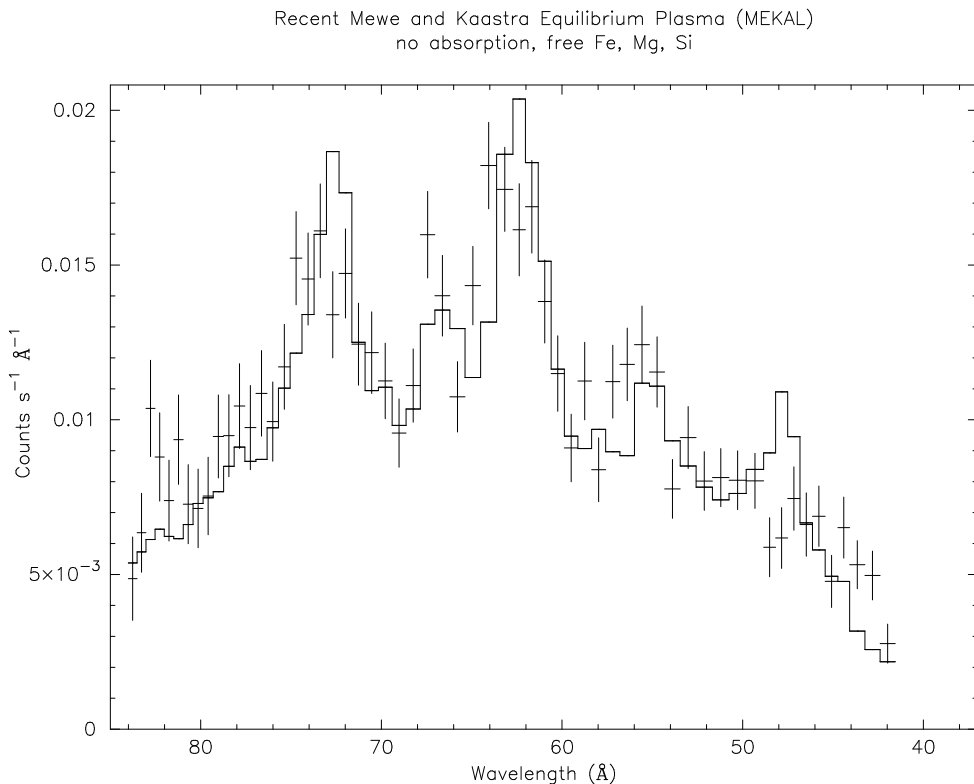


Figure 6: DXS Puppis spectrum best fit to a single temperature Mewe and Kaastra equilibrium plasma model.

## Spectral Fits: Equilibrium

Figure 6 shows the DXS spectrum of the Puppis region fit with a single temperature equilibrium plasma model (Kaastra 1992). In this fit, the temperature, normalization, and abundances of Fe, Mg, and Si were free parameters. The best fit temperature is  $1.1 \times 10^6$  K and the best fit abundances are in the range of 0.1 to 0.4 of solar. The reduced  $\chi^2$  of this fit is 3.0. Raymond and Smith equilibrium models, based on the 1993 revision of the code, fit no better.

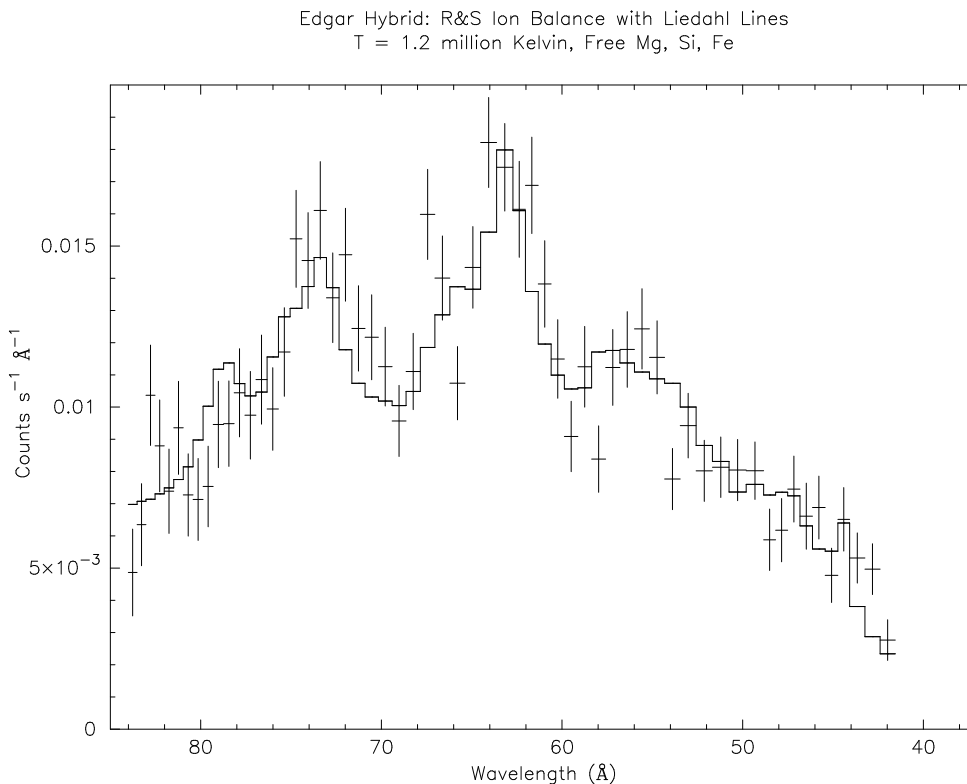


Figure 7: Puppis spectrum fit to equilibrium model using Raymond and Smith equilibrium ionic concentrations but Liedahl line lists.

## Spectral Fits: More Atomic Physics

Recent work by D. Liedahl has added significantly to the number of lines at this temperature in the DXS pass band. The model in Figure 7 is the result of using Raymond and Smith equilibrium ionic concentrations but with Liedahl's line lists. The temperature, normalization and abundances of Fe, Mg, and Si were free parameters. The reduced  $\chi^2$  of this fit is 2.0, an improvement over the Mewe and Kaastra case, but still not a formally acceptable fit.

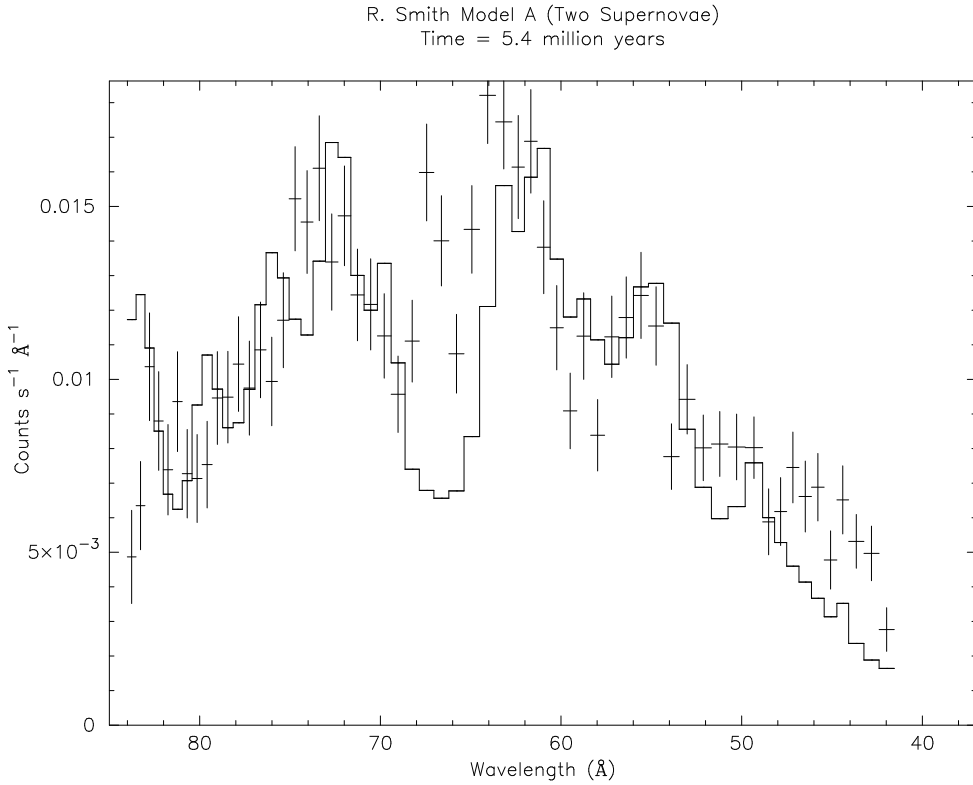


Figure 8: Puppis spectrum fit to R. Smith model A, 5.4 million years.

## Spectral Fits: Non-Equilibrium

R. Smith has constructed non-equilibrium models consisting of emission from multiple supernova remnants. His code includes dust cooling and sputtering, the possibility of spatially varying abundances, and thermal conduction. Figure 8 shows the results of one of his models which calculates the emission as seen inside the superbubble caused by two supernova explosions. The reduced  $\chi^2$  of this fit is a disappointing 6.4.

Although R. Smith's model is more complex than a simple depleted equilibrium plasma emission model, it relies on the incomplete atomic data of the 1993 update to the Raymond and Smith plasma emission code.

## Conclusion

The essential and important result of DXS is the confirmation of the hypothesis, set forth in Williamson et al. (1974), that the 1/4 keV component of the diffuse X-ray background is composed largely of emission lines, most likely emitted from gas heated to temperatures near one million degrees. Precise physical understanding of the emission has, thus far, eluded us as available global models and state-of-the-art atomic data have yet to be fully integrated. The fact that fits of equilibrium plasma models to the data are improved by allowing the concentrations of Fe, Si, and Mg to float is suggestive that the emission arises from regions of the interstellar medium containing dust grains.

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